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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1071

DETERMINATION OF THE ACTUAL CONTACT SURFACE OF A BRUSH CONTACT

By Ragnar Holm

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SUMMARY

The number of partial contact surfaces of a brush-ring contact is measured by means of a statistical method. The particular brush is fitted with wicks - that is, insulated and cemented cylinders of brush material, terminating in the brush surface. The number of partial contact surfaces can be computed from the length of the rest periods in which such wicks remain without current. Resistance measurements enable the determination of the size of the contact surfaces. The pressure in the actual contact surface of a recently bedded brush is found to be not much lower than the Brinell hardness of the brush.

INTRODUCTION

While it is probably generally conceded that the momentary contact surface between a carbon brush and the respective ring or commutator on electrical machines is but a fraction of the bedded surface, the number and extent of partial surfaces into which the contact surface is divided, was unknown. After many attempts the answer has now been found. The requisite calculations were made with certain simplifying theorems, which however detract little from the final result.

Visualize the momentary actual contact surface as consisting of n small partial surfaces, which on the average

*"Eine Bestimmung der wirklichen Berührungsfläche eines Bürstenkontaktes." Wissenschaftliche Veroffentlichungen aus den Siemens-Werken, vol. 17, no. 4, 1938, pp. 43-47.

no part alongside of the spreading resistance in the carb[illegible]. The resistance to spreading in the copper is, in either ca[illegible] negligible, and the measurement of the contact resistance [illegible] then gives the resistance to spreading in the brush.

It is no easy matter to secure a sufficiently clean ring surface; an added difficulty is that the bedded brush surface has a film of graphite flakes which here has a disturbing contact resistance. Careful polishing and amalgamating of the ring surface proved satisfactory. Check measurements on a silver ring with brushes without wicks were also made. To avoid the disturbance due to the graphite layer, the brush should be wiped and the measurements made soon thereafter.

Next, visualize the partial surfaces as small circles with radius a_1, a_2, a_3 ... and with mutual distances, which are great in respect to the a values. The total resistance to spreading is then

$$R = \frac{\rho}{4 \Sigma a} \tag{3}$$

with ρ indicating the specific electric resistance of the brush material.

Now, the partial surfaces are, in general, certainly not circles, but usually somewhat elongated. If they were ellipses, three times as long as wide, R would diminish by a form factor 0.9. (The one-sided spreading resistance of an ellipse with semiaxes α and β is $R = \frac{\rho}{2\pi\alpha} K(k)$, where K is the complete elliptic integral of the first order and the modulus $k = \sqrt{\frac{\alpha^2 - \beta^2}{\alpha}}$.) The form factor therefore does not amount to much, neither does it vary much if a somewhat different elongation were assumed, or if the different partial surfaces had a different elongation. The chosen form factor 0.9 should be a close average of the actual surface distortion.

The average pressure p in the actual contact surface is to be estimated. This requires certain assumptions regarding the distribution of the a values.* Consider, first,

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*Originally the calculation was carried out in simplified form on the premise of equal contact areas of average magnitude. But Dr. E. Spenke pointed out in a discussion, (Footnote continued on next page)

two extreme cases: 1) that all a are equal, 2) that $a_1 = \epsilon$, $a_2 = 2\epsilon$, $a_3 = 3\epsilon$, and so forth.

In general the looked-for pressure p is:

$$p = \frac{P}{\Sigma\ (\pi a^2)} \tag{4}$$

where P equals pressure on the contact.

It should be borne in mind that the same resistance R is the basis of both cases 1 and 2, and that therefore, owing to equation (3) or the subsequent equation (9):

$$n\ a = \sum_{\nu=1}^{\nu=n} (\nu\ \epsilon) = \tfrac{1}{2}\ n\ (n + 1)\ \epsilon \tag{5}$$

Considering further that

$$\sum_{\nu=1}^{\nu=n} (\nu\ \epsilon)^2 = \frac{1}{6}\ (2n + 1)\ (n + 1)\ n\ \epsilon^2 \tag{6}$$

a simple calculation yields the ratio of the pressures p_2 and p_1 of the two hypothetical extreme cases at

$$\frac{p_2}{p_1} = \frac{\pi\ n\ a^2}{\pi\ \ \Sigma(\nu\ \epsilon)^2} = \frac{3\ (n + 1)}{2\ (2n + 1)} \tag{7}$$

Then, for $n = 5$, for example,

$$\frac{p_2}{p_1} = 0.82$$

and for $n = 20$

$$\frac{p_2}{p_1} = 0.77$$

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that in the case of varying size of contact surfaces the application of the simple method would give two high-contact pressures. For this reason the previous calculation was made under generalized assumptions.

In reality there might occur a certain accumulation of the a values, so that the reality, so to say, lies between the two cases 1 and 2. And since the pertinent n values lie in the just-cited order of magnitude, a proper allowance for the dissimilarity of the a surfaces should accrue with the use of the following mean pressure equation

$$p = \frac{P\ 0.9}{n\ \pi a^2} \tag{8}$$

where a is defined by the equation

$$R = \frac{0.9\ \rho}{4n\ a} \tag{9}$$

This a is therefore a mathematical quantity that results when all partial surfaces are put equal and when the actual complicity is represented by the two coefficients put equal to 0.9. Foregoing any special consideration of the occasionally mutual approach of the partial surfaces, it is simply noted that this merely results in a slightly greater resistance, which, however, is very little in this instance, because on the comparatively large bedded surface the individual contact partial surfaces should on an average fall fairly far apart. The equations (8) and (9) are conclusive. Hence, after n has been determined on the basis of equation (2), the value a is obtained from equation (9) and p from equation (8). The data are reproduced in table 1.

TABLE 1

NUMBER OF INDIVIDUAL CONTACT SURFACES AND THEIR AVERAGE EXTENT IN SLIDING CONTACTS. $\rho = 4.31 \times 10^{-3}$ cm Ω

Number	Diameter of wick (cm)	F bedded brush surface (cm²)	P pressure on contact (g)	R spreading resistance (Ω)	x average number of partial surfaces touching wick	2a average diameter of partial surfaces (10^{-3} cm)	n number of partial surfaces	p contact pressure (t cm²)
1	0.38	2.1	1100	0.012 to .015	1.0	9 to 7	18	0.9 to 1.3
2	.38	1.8	1100	.018	.7	10	11	1.2
3	.38	1.7	500	.003	.37	12	5.5	.8
4	.27	1.5	435	.025	.43	7	11	.93

Figure 1 shows a section of a record with three wicks, their setting in the sliding surface being as shown in figure 2. The particular record averaged for the wicks

$$W(0) = 0.69$$

corresponding to $\bar{x} = 0.37$. The contact force was 500 g; the brush was negative. The marked scatter is attributable in part to the nature of the contacts, and in part to the type of measurement. The respective contact resistance itself varied considerably from one position to the other on the ring, occasionally as much as 3:1. Table 1 contains average values of the lowest resistances. The greatest discrepancies, presumably caused by unclean surfaces, were omitted. The number n of the partial surfaces certainly varied also considerably from place to place. The values of x ranged from 0.25 to 0.5.

As already stated, the contact resistance measurements had to be made on the quite recently cleaned contact ring against brush, hence always under somewhat different conditions than obtained for the recording, for which only a slightly bedded brush proved satisfactory.

According to the foregoing, the n values are quite reliable. They are such as actually occur in contacts of this type. The a and p values are less dependable, since it is likely that occasionally disturbing layers made the resistances appear somewhat too great; besides, the correctly bedded condition had not obtained as yet at the time of the measurement. As a result, the recorded pressure p is unusually high and approaches the Brinell hardness of the particular electro-graphite, which was 1.4 t/cm^2. For the recording of p on brushes bedded for some time, an entirely different method has been developed, concerning the application of which a report is to be published later.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

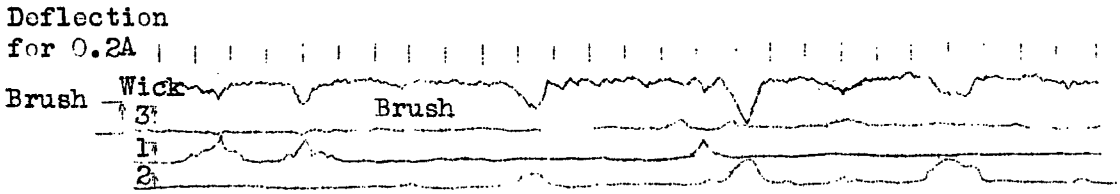

Figure 1.- Loop oscillogram of currents passing through three wicks and the brush.

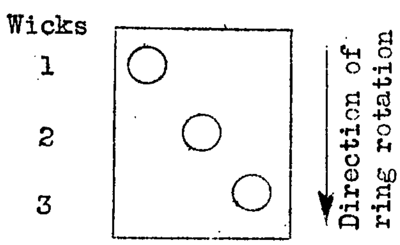

Figure 2.- Disposition of wicks, viewed from the sliding surface.